Optimal Loading Range for the Development of Peak Power Output in the Hexagonal Barbell Jump Squat

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Abstract

Turner, TS, Tobin, DP, and Delahunt, E. Optimal loading range for the development of peak power output in the hexagonal barbell jump squat. *J Strength Cond Res* 29(6): 1627–1632, 2015—Recent studies indicate that the utilization of the hexagonal barbell jump squat (HBJS) compared with the traditional barbell jump squat may offer a superior method of developing peak power. The notion that a single optimal load may be prescribed in training programs aiming to develop peak power is subject to debate. The purpose of this study was to identify the optimal load corresponding with peak power output during the HBJS in professional rugby union players. Seventeen professional rugby union players participated in this study. Participants performed 3 unloaded countermovement jumps on a force plate and 3 HBJS at each of the following randomized loads: 10, 20, 30, and 40% of box squat 1 repetition maximum (1RM). Peak power output was the dependent variable of interest. A one-way repeated measures analysis of variance was conducted to compare peak power output across each load. Peak power output was the dependent variable of interest. A significant main effect for load was observed (Wilk's Lambda = 0.11, $F_{(4,13)} = 18.07$, $p < 0.01$, partial $\eta^2 = 0.88$). Results of the Bonferroni-adjusted pairwise comparisons indicated that peak power output in the HBJS is optimized at a load range between 10 and 20% of box squat 1RM. The results of this study indicate that the use of the HBJS with a training load between 10 and 20% of box squat 1RM optimizes peak power output in professional rugby union players.

Key Words speed-strength, ballistic, jump testing

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Introduction

The relationship between muscular power and expressions of dynamic athletic performance in sport has been well documented (3,4,12,14,16). Consequently, methods and strategies aimed at improving lower body muscular power are an important consideration for the strength and conditioning practitioner. The jump squat (JS) is a common exercise for training lower body power (3,19). Cormie et al. (8) have recommended the JS as the optimal lower body exercise for maximizing peak power output in an elite athletic population. However, there is considerable ambiguity in the literature concerning the most appropriate methodology (6,7,11), loading strategy (3–5,9,10,14,24), and optimal variation of the JS exercise (19,22) relative to the generation of peak power output.

The inclusion or exclusion of body mass (BM) in the calculation of power output during the JS is a pertinent issue (6,11). It is now widely acknowledged that BM needs to be included as part of the system load (BM and external load) as it represents a significant portion of the overall load that has to be accelerated (4,6–8,11). The exclusion of BM in the calculation of power output during the JS leads to a misrepresentation of power output in the load-power relationship (6,7,11). There has also been some debate as to whether mean or peak power should be reported in research studies. Because of the moderate to strong correlation reported in the literature between peak power output and athletic performance (17,20), it is logical to report this parameter (11). The majority of recent studies have reported peak power including BM in their calculations. Consequently, much of this research has reported 0% of 1 repetition maximum (1RM) or in other words BM alone, as the optimal load for peak power output in the JS (1,4,6–8,10).

The notion that a single optimal load may be used in training programs aiming to develop peak power has been subject to considerable debate (5). Some researchers have reported an optimal load for the generation of peak power despite a lack of statistically significant differences between a range of load intensities (8,10). For example, Dayne et al. (10) reported 0% of 1RM squat strength (BM) as the optimal load in the JS, despite the fact that there was no statistically significant difference between peak power output at 0 and 20% of 1RM. However, the peak power output recorded at both 0 and 20% of 1RM were significantly higher than those recorded at 40, 60, and 80% of 1RM. Therefore, based on the statistical analysis in this study, a range of 0–20% of 1RM is the optimal load "range" with the prescription of a single optimal load deemed inappropriate. Furthermore, the case for a single optimal load is further compounded by individual variation in the load that maximizes acute peak power (14), particularly in elite athletes (9,24). As such, generic recommendations regarding a single optimal load for the development of peak power are likely ill-advised.

It is widely recognized that the optimal load for peak power output is dependent on the nature of the exercise (8,13,14). Previous studies investigating peak power output in the JS exercise have traditionally reported the use of a barbell in the methodology (1,4,6–8,10,24). However, more recently Swinton et al. (22) reported that the hexagonal barbell jump squat (HBJS) produced significantly greater power output at 20% of 1RM in comparison with the traditional barbell jump squat (BBJS) variation. The authors concluded that there was a load position effect on peak power values, and that the hexagonal barbell variation may be safer and more effective than the use of a traditional barbell. The HBJS may offer a biomechanical advantage over the BBJS, allowing for improved kinematics and kinetics (21,22,25). Despite reporting that 20% of 1RM was the single optimal load for peak power output, Swinton et al. (22) only reported loads of 0, 20, 40, and 60% of 1RM. It is therefore conceivable that the optimal range of loads could span above and below the 20% value (e.g., 10–30% 1RM), which requires further investigation.

Despite a plethora of research, there is still considerable debate concerning the most appropriate loading range to develop peak power. Much of the research has focused on the traditional BBJS variation. However, recent evidence of the superiority of the HBJS in the generation of peak power output (22) and its increasing popularity in the strength and conditioning community make investigating the optimal load range in this exercise a matter of significant importance. Therefore, the aim of this study was to determine the load range that elicits the greatest HBJS peak power in elite rugby union players through the analysis of HBJS with loads at 0, 10, 20, 30, and 40% of 1RM. It was hypothesized that peak power at 10, 20, and 30% of 1RM, although not significantly different from each other, would be significantly greater than 0 and 40% of 1RM. A secondary hypothesis was that the load at which peak power occurs would have large intersubject variability.

Methods

Experimental Approach to the Problem

This study used a within-subject repeated measures design. Participants performed a series of randomized maximal effort jumps across a range of prescribed loads to determine the load range at which peak power was optimized. Loaded jumps were performed with the hexagonal barbell with external loads equivalent to 10% (HBJS 10%), 20% (HBJS 20%), 30% (HBJS 30%), and 40% (HBJS 40%) of predetermined box squat 1RM. The 0% of 1RM (BM) condition was performed in the same manner as a countermovement jump, which closely resembles the HBJS variation (with hands positioned on the hips rather than on the bar). Jumps were executed in a randomized and balanced order to rule out an order effect. All testing was performed on a portable force plate (HUR Labs, Tampere, Finland). The BM of each participant was included in all subsequent calculations. Peak power was the independent variable used in the analysis. The *SEM* was applied to the peak power values of each individual across the load range to determine meaningful differences between conditions.

Subjects

Seventeen elite male rugby union players from a range of different playing positions volunteered to participate in the study (Table 1). Participants were contracted to a professional rugby union club playing in the Pro12 competition. However, none of the participants had yet represented their country at test rugby union level at the time of testing. Participants were recruited on the basis that they were free from any injury or any training restrictions, as verified by the club physiotherapist and had a minimum of 2 years of structured training experience under the supervision of a club strength and conditioning coach. All participants regularly performed maximal effort unloaded and loaded jumps as part of their training and were familiar with and technically proficient in the HBJS variation. Testing was performed during the in-season period, where typical weekly training volume included 3 resistance training sessions, 3 team practice sessions, and a competitive game at the end of the week. However, participants were tested after a deload period of 3 days to allow for peak performance in all tests. This study was approved by the University College Dublin Human Research Ethics Committee. Written informed consent was obtained from all participants before testing.

Table 1. Participant characteristics.*

Variables	Mean ± *SD*
Age (y)	20.8 ± 1.1
Body mass (kg)	98.7 ± 10.4
Height (cm)	185.5 ± 6.1
1RM box squat (kg)	180.4 ± 18.8

*RM = repetition maximum.

Procedures

Testing took place on 2 days, separated by 72 hours to allow for full recovery. On day 1, maximal lower body strength was assessed, whereas lower body power was assessed on day 2. Participants were asked to maintain and replicate their normal food and fluid intake before both testing dates and to refrain from alcohol consumption for at least 24 hours and caffeine for at least 3 hours. Before testing, participants performed their normal daily battery of physical monitoring assessments, which included bodyweight measurement, a sit and reach test, groin adductor squeeze test, and hip internal rotation measures. Any participants who fell outside their established norms in these assessments were removed from testing. All testing took place between 9 AM and 11 AM to control for any diurnal variation and to reflect their normal training time.

Strength Assessments. Maximal strength was assessed using the box squat exercise using methods previously outlined (1). Participants completed a supervised and standardized dynamic warm-up protocol, which consisted of leg swings (10 reps), bodyweight squats (10 reps), bodyweight alternate leg lunges (10 reps each leg), and bodyweight single leg stiff leg deadlifts (10 reps each leg). Participants then completed 4–5 submaximal sets of 3–5 repetitions in the box squat, gradually building towards an estimated 1RM load. They then performed 1 repetition at the estimated load and if successful, the load was increased in 5 kg increments until the maximum lift was achieved. Three minutes of rest was allocated between each set. Using a standard 20-kg Olympic barbell and weight plates (Werk San, Ankara, Turkey), participants lowered themselves under control to a sitting position on a box and then returned to the standing position. The height of the box was adjusted so that the top of each individual's thighs were parallel to the floor when in the seated position. Each repetition was visually monitored and supervised by a strength and conditioning coach.

Power Assessments. Participants completed the supervised and standardized dynamic warm-up protocol as previously described. All jump conditions (0, 10, 20, 30, and 40% of predetermined box squat 1RM) were performed in a randomized order with participants instructed to jump with maximal effort on each trial. The unloaded condition was conducted as a countermovement jump with a protocol similar to those used in previously published research (15,23). Participants, began with hands on hips to eliminate any upper body involvement and to closely replicate the positioning of the arms in the HBJS, were instructed to squat and immediately jump as high as possible. Loaded jumps with a 15-kg hexagonal barbell (Watson Gym Equipment, Somerset, United Kingdom) were performed as described by Swinton et al. (22). Participants, began with the hexagonal barbell at arm's length, were instructed to squat and immediately jump as high as possible. Participants descended to a half squat position for all conditions (approximately 60° of hip flexion, knee joint angle was not controlled for), which was visually monitored by the same researcher. Participants were required to repeat the trial if they did not achieve the required depth, as per the protocol detailed in Swinton et al. (22) or in the event of the bar accidently touching the floor. Subjects performed 3 trials to ensure intratrial reliability with a 60-second rest between each trial and a 3-minute rest period between sets to allow for full recovery. The coefficient of variation (CV) and intraclass correlation coefficient (ICC) and associated *SEM* for each loading condition was as follows: 0% CV range = 0.41–7.72, ICC = 0.96, *SEM* = 111.75 W; 10% CV range = 0.49–7.92, ICC = 0.96, *SEM* = 133.78 W; 20% CV range = 0.53–4.65, ICC = 0.98, *SEM* = 90.62 W; 30% CV range = 0.11–10.72, ICC = 0.96, *SEM* = 135.45 W; 40% CV range = 0.53–8.04, ICC = 0.98, *SEM* = 118.48 W. The HBJS with the highest peak power from each set was used for statistical analysis. Each HBJS was performed with participants standing on a force plate (HUR Labs) with data recorded at a frequency of 1,200 Hz and interfaced with a laptop computer. The HUR Labs system was calibrated before each testing session. A built-in charge amplifier was used for data collection of the ground reaction force-time history of each jump condition. Ground reaction force data were passed through a fourth-order zero-phase Butterworth low-pass digital filter with a 5 Hz cutoff frequency. Data were analyzed using the HUR Labs software with peak power output (watts) being the dependent variable of interest. Peak power output was automatically calculated by the HUR Labs software in accordance with the methods described by Sayers et al. (18), whereby peak power (W) = 60.7 jump height (cm) + 45.3 BM (kg) − 2055.

Statistical Analyses

A one-way repeated measures analysis of variance was conducted to compare peak power output under each of the following conditions: (a) 0% (BM), (b) HBJS 10%, (c) HBJS 20%, (d) HBJS 30%, and (e) HBJS 40%. Statistical analyses were conducted in IBM SPSS Statistics 20 (IBM Ireland Ltd., Dublin, Ireland). The level of statistical significance was set at $p \leq 0.05$. When a significant main effect was observed for condition, a Bonferroni-adjusted pairwise comparison was undertaken. For each load, we established the SEM and hence used this as a "threshold" to determine whether each individual participant's peak power output at each load differed substantially from the 4 other loads. Consequently, it was possible to ascertain whether peak power output for each individual participant occurred at a single load or across multiple loads considering the aforementioned SEM results.

Results

The peak power output under each condition is summarized in Table 2. There was a significant main effect for condition, Wilk's Lambda = 0.11, $F_{(4,13)} = 18.07$, $p < 0.01$, partial $\eta^2 = 0.88$.

TABLE 2. Peak power output for each loaded condition.*

Condition	Peak power (W)	95% CI lower bound	95% CI upper bound
0%	5127.43 ± 644.12†‡§‖	4796.27	5458.63
HBJS 10%	5758.44 ± 648.29‖¶	5425.12	6091.76
HBJS 20%	5783.40 ± 589.27§‖¶	5480.42	6068.38
HBJS 30%	5604.40 ± 651.96‡¶	5269.19	5939.61
HBJS 40%	5450.78 ± 715.52†‡¶	5082.89	5818.67

*CI = confidence interval; HBJS = hexagonal barbell jump squat.
†Significantly different HBJS 10%.
‡Significantly different HBJS 20%.
§Significantly different HBJS 30%.
‖Significantly different HBJS 40%.
¶Significantly different from 0%.

Results of the Bonferroni-adjusted pairwise comparisons indicated that peak power output for the 0% condition differed significantly from the HBJS 10% (mean difference = −630 W, 95% confidence interval [CI] = −839.05 to −422.92), HBJS 20% (mean difference = −655.94 W; 95% CI = 871.59 to −440.30), HBJS 30% (mean difference = −476.94 W; 95% CI = −710.47 to −243.42), and HBJS 40% (mean difference = −323.33 W; 95% CI = −608.27 to −38.39) conditions ($p < 0.01$) (Table 2).

The HBJS 10% condition was significantly different from the 0% condition (mean difference = 630.99 W; 95% CI = 422.92 to 839.05; $p < 0.01$) and the HBJS 40% condition (mean difference = 307.61 W; 95% CI = 32.94 to 582.36; $p \leq 0.05$) but not significantly different from the HBJS 20% and HBJS 30% conditions ($p > 0.05$).

The HBJS 20% condition was significantly different from the 0% condition (mean difference = 655.94 W; 95% CI = 440.30 to 871.59; $p < 0.01$), the HBJS 30% condition (mean difference = 179.00 W; 95% CI = 15.57 to 342.42; $p \leq 0.05$), and the HBJS 40% condition (mean difference = 332.61 W; 95% CI = 76.14 to 589.08; $p \leq 0.05$). The HBJS 20% condition did not differ significantly from the HBJS 10% condition ($p > 0.05$).

The HBJS 30% condition was significantly different from the 0% condition (mean difference = 476.94 W; 95% CI = 243.42 to 710.47; $p < 0.01$) and the HBJS 20% condition (mean difference = −179.00 W; 95% CI = −342.42 to −15.57; $p \leq 0.05$) but not significantly different from the HBJS 10% and HBJS 40% conditions ($p > 0.05$).

The HBJS 40% condition was significantly different from the 0% condition (mean difference = 323.33 W; 95% CI = 38.39 to 608.27; $p \leq 0.05$), the HBJS 10% condition (mean difference = −307.65 W; 95% CI = −582.36 to −32.94; $p \leq 0.05$), and the HBJS 20% condition (mean difference = −332.61 W; 95% CI = −589.08 to −76.14; $p < 0.01$). The HBJS 40% condition was not significantly different from the HBJS 30% condition ($p > 0.05$).

For each participant, variability between loading conditions was accounted for by determining the SEM of each load. This allowed for the determination of whether meaningful differences between the various loading conditions existed. Therefore, it was possible for participants to have more than 1 optimal load. Of the 17 participants included in this study, 15 produced optimal power values with more than 1 load. The 0% condition was not optimal for any of the 17 participants, the HBJS 10% condition was optimal for 14 of the participants, the HBJS 20% condition was optimal for 14 of the participants, the HBJS 30% condition was optimal for 9 of the participants, while the HBJS 40% condition was optimal for 4 of the participants.

Discussion

The results of this study demonstrate that at a group level, peak power in the HBJS is optimized at a range of loads between 10 and 20% of 1RM in elite rugby union players. There was no significant difference in peak power between 10 and 20% of 1RM, but both conditions produced higher peak power outputs than 0, 30, and 40% of 1RM. As such, the primary hypothesis of the study was partially confirmed, and there exists an optimal load range between 10 and 20% of 1RM for the generation of peak power in the HBJS. These findings expand on the previous research of Swinton et al. (22) who recommended 20% of 1RM as the optimal load in this exercise, despite the fact that they did not investigate outputs at 10 and 30% of 1RM. Contrary to the original hypothesis, 30% of 1RM produced significantly lower peak power values than 20% of 1RM and hence is not be recommended in the load range for the generation of peak power. The secondary hypothesis of the study was also confirmed, with the load that maximizes peak power being highly individual. Peak power was optimized at a range of loads for the majority of participants.

The strength and power levels of the participants in this study compare favorably with those reported elsewhere in the literature. The box squat performance reported here is similar (2) or superior (1) to that reported in other investigations involving professional rugby union players. The peak power performance of the participants in this study is also superior to that reported elsewhere in 47 professional rugby union players (4). However, the study of Bevan et al. (4) involved the BBJS variation. When using the HBJS variation, Swinton et al. (22) reported peak power values below those of this study. Therefore, the population in this study is accurately described as elite within the context of similar studies involving rugby union players.

In this study, 0% of 1RM produced significantly lower power values than all loaded conditions. This is in stark contrast to recent research, which has consistently reported that the 0% of 1RM squat (BM only) jumping condition produces higher peak power values in comparison with a range of BBJS loads (1,4,6–8,10). These findings support those of Swinton et al. (22) and suggests that when loaded jumps are completed with a hexagonal barbell (i.e., HBJS), peak power output is higher than the unloaded condition. They also reported that the HBJS condition produced superior power outputs to the BBJS condition with the same load. It is therefore clear that the load positioning during the HBJS offers a distinct advantage over the BBJS when attempting to optimize peak power. Swinton et al. (22) speculated that the change in load position may enable athletes to closely resemble their unloaded jump technique in the HBJS condition compared with the BBJS. In other words, the BBJS method may require a greater deviation from the natural kinematics and joint contributions of unloaded jumping, therefore resulting in compromised kinetic values. Argus et al. (1) report that with the addition of an increasing external load in the BBJS variation, depth in the countermovement portion of the jump was reduced, which may result in compromised power outputs with the addition of load. In this study, where countermovement depth was visually monitored, the addition of load actually improved power output in comparison with the 0% of 1RM load, possibly due to the more favorable load positioning. Swinton et al. (22) also suggest that the altered load positioning of the HBJS may be safer and more comfortable in comparison with the BBJS with comparable loads, with the chances of injury to the cervical spine reduced. Therefore, from the point of view of the practitioner, when selecting speed-strength strategies for the development of peak power with light loads, the HBJS could be considered as a viable exercise selection.

The findings of this study suggest that the load range from 10 to 20% of 1RM in the HBJS produce significantly higher peak power values than either the 0 or 40% of 1RM condition. It is worth noting that peak power may be optimized at a wider load range as intensities between 1 and 9% of 1RM and 21–29% of 1RM were not tested. Swinton et al. (22) reported 20% 1RM to be the optimal load in the HBJS but failed to examine power outputs at 10 and 30% 1RM. Therefore, this study expands on the findings of Swinton et al. (22) and suggests that power output at 10 or 20% of 1RM are not statistically different. However, an unexpected finding was the significant difference between peak power at 20 and 30% of 1RM. Despite there being no significant difference between 10 and 30% of 1RM, it is statistically accurate to exclude 30% of 1RM from the optimal load range. Some researchers have made recommendations of a single optimal load in the generation of peak power (4,8) despite in some cases, statistically insignificant findings being observed over a range of loads. For example, Cormie et al. (8) recommended BM as the optimal JS load despite the fact that it did not differ significantly from all other intensities reported. Similarly, Dayne et al. (10) suggested that 0% of 1RM (BM) to be the optimal load for peak power in the BBJS, despite this load not being statistically different to a 20% of 1RM load. The disparity between the statistical findings and the practical applications reported for these studies could mislead the reader. The recommendations of this study, however, are linked to the findings in suggesting an optimal load range of 10–20% of 1RM in the generation of peak power in the HBJS.

A novelty of this study is the consideration of power outputs across a range of loads for each individual participant. To further highlight the potentially misleading nature of recommending a single optimum load, *SEM* was applied to the data to investigate if one load was meaningfully different from another. Only 2 of the 17 (12%) participants in this study expressed peak power values at a single load condition that was meaningfully different from all other loads. In terms of a generic recommendation, 14 of the 17 participants (82%) in this study produced their absolute highest power value at either 10 or 20% 1RM. However, the findings also highlight the need to consider whether the absolute load is meaningfully different to other loading conditions. It is likely that a range of loads will optimize the generation of peak power in the majority of participants (88%).

It has been suggested (3,13,14) that optimal load fluctuates depending on the strength level and training status of the individual athlete throughout a competitive season, thus reinforcing the value of regular assessments. While the identification of an individual's optimal load would be ideal with a large number of athletes in a team setting, this may not be feasible for the practitioner. The recommended load range of 10–20% of 1RM accounts for the majority (i.e., 82%) of the athletic population investigated in this study and provides a loading strategy with strong practical application in the team sport setting. However, to improve the accuracy of the assessment, the use of *SEM* in interpreting the meaningful differences between loading conditions is recommended. In doing so, it is likely that the majority of participants will have a number of loading conditions at which peak power is optimized.

A potential limitation of this study may be the fact that HBJS loads were derived from % 1RM values of the box squat. This is similar to the protocol of Swinton et al. (22) who also derived %1RM values in the HBJS from the back squat exercise. However, the box squat is a common lower body exercise with which this group of athletes was familiar, and it was therefore deemed the most reliable and the safest measure to differentiate between the different strength levels of each participant. If loading intensities in the HBJS were derived from 1RM values in the hexagonal barbell deadlift, this will likely change the %1RM values at which peak power occurs. However, it is believed that the absolute loading range at which peak power is optimized in the HBJS will be consistent regardless from which exercise the percentiles are derived.

The results of this study indicate that peak power output in the HBJS is optimized at a load range between 10 and 20% of box squat 1RM. This is in contrast to a recent trend in the research reporting peak power in the BBJS to be optimized at 0% of 1RM (1,4,6–8,10). Instead, when loads are applied with a hexagonal barbell, a range of loads above 0% of 1RM yield the highest peak power outputs. This validates the use of the increasingly popular hexagonal barbell as a method for improving the kinetics and kinematics of the JS exercise. However, this is an acute study and the possibility that a training intervention using the HBJS might improve athletic performance needs to be verified with a longitudinal training study. The highly variable nature of the individual results also indicates the importance of determining the optimal load range for peak power in the HBJS for each athlete. In working environments, where the determination of an individual's optimal load is not expedient, the authors strongly recommend the application of a training load in the HBJS that covers the 10–20% of 1RM range when attempting to maximize power output. It is important to note that the findings of this study may be specific to the population cohort used (i.e., professional rugby union players), and hence additional research is required to verify the same findings in other athletic populations.

Practical Applications

The results of this study highlight that peak power output in the HBJS occurs under loaded conditions. This contrasts with recent findings in the BBJS where power output was reported to be reduced with the addition of external loads. It is widely accepted that a balanced program requires training at a variety of loads along the force-velocity curve. When attempting to target acute peak power output with light loads, the authors of this study recommend the use of the HBJS with the load range between 10 and 20% of 1RM box squat. Furthermore, it is strongly recommended that individual optimal load ranges are identified where possible. However, in a team sport setting where determination of individual optimal load range may be deemed impractical, the recommendation of a load range between 10 and 20% of 1RM should be sufficient for the majority of athletes.

References

1. Argus, CK, Gill, ND, Keogh, JWL, and Hopkins, WG. Assessing lower-body peak power in elite rugby union players. *J Strength Cond Res* 25: 1616–1621, 2011.
2. Argus, CK, Gill, ND, Keogh, JWL, Hopkins, WG, and Beaven, CM. Changes in strength, power and steroid hormones during a professional rugby union competition. *J Strength Cond Res* 23: 1583–1592, 2009.
3. Baker, D, Nance, S, and Moore, M. The load that maximizes the average mechanical power output during jump squats in power-trained athletes. *J Strength Cond Res* 15: 92–97, 2001.
4. Bevan, HR, Bunce, PJ, Owen, NJ, Bennett, MA, Cook, CJ, Cunningham, DJ, Newton, RU, and Kilduff, LP. Optimal loading for the development of peak power output in professional rugby players. *J Strength Cond Res* 24: 43–47, 2010.
5. Chiu, LZF. Does an optimal load exist for power training? *Strength Cond J* 30: 67–69, 2008.
6. Cormie, P, McBride, JM, and McCaulley, GO. The influence of body mass on calculation of power during lower-body resistance exercises. *J Strength Cond Res* 21: 1042–1049, 2007.
7. Cormie, P, McBride, JM, and McCaulley, GO. Validation of power measurement techniques in dynamic lower body resistance exercises. *J Appl Biomech* 23: 103–118, 2007.
8. Cormie, P, McCaulley, N, Triplett, T, and McBride, JM. Optimal loading for maximal power output during lower-body resistance exercises. *Med Sci Sports Exerc* 39: 340–349, 2007.
9. Cronin, J and Sleivert, G. Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Med* 35: 213–234, 2005.
10. Dayne, AM, McBride, JM, Nuzzo, JL, Triplett, T, Skinner, J, and Burr, A. Power output in the jump squat in adolescent male athletes. *J Strength Cond Res* 25: 585–589, 2011.
11. Dugan, EL, Doyle, TLA, Humphries, B, Hasson, CJ, and Newton, RU. Determining the optimal load for jump squats: A review of methods and calculations. *J Strength Cond Res* 18: 668–674, 2004.
12. Duthie, G, Pyne, D, Marsh, DJ, and Hooper, S. Sprint patterns in rugby union players during competition. *J Strength Cond Res* 20: 208–214, 2006.
13. Kawamori, N, Crum, AJ, Blumert, PA, Kulik, JR, Childers, JT, Wood, JA, Stone, MH, and Haff, GG. Influence of different relative intensities on power output during the hang power clean: Identification of the optimal load. *J Strength Cond Res* 19: 698–708, 2005.
14. Kawamori, N and Haff, GG. The optimal training load for the development of muscular power. *J Strength Cond Res* 18: 675–684, 2004.
15. Kirkpatrick, J and Comfort, P. Strength, power and speed qualities in English junior elite rugby league players. *J Strength Cond Res* 27: 2414–2419, 2013.
16. Lockie, RG, Murphy, AJ, Knight, TJ, and Janse De Jonge, XAK. Factors that differentiate acceleration ability in field sport athletes. *J Strength Cond Res* 25: 2704–2714, 2011.
17. Requena, B, Garcia, I, Requena, F, De Villarreal, ES, and Cronin, JB. Relationship between traditional and ballistic squat exercise with vertical jumping and maximal sprinting. *J Strength Cond Res* 25: 2193–2204, 2011.
18. Sayers, SP, Harackiewicz, DV, Harman, EA, Frykman, PN, and Rosenstein, MT. Cross-validation of three jump power equations. *Med Sci Sports Exerc* 31: 572–577, 1999.
19. Schuna, JM and Christensen, BK. The jump squat: Free weight barbell, Smith machine, or Dumbbells? *Strength Cond J* 32: 38–41, 2010.
20. Sleivert, G and Taingahue, M. The relationship between maximal jump-squat power and sprint acceleration in athletes. *Eur J Appl Physiol* 91: 46–52, 2004.
21. Swinton, PA, Stewart, A, Agouris, I, Keogh, JWL, and Lloyd, R. A biomechanical analysis of straight and hexagonal barbell deadlifts using submaximal loads. *J Strength Cond Res* 25: 2000–2009, 2011.
22. Swinton, PA, Stewart, AD, Lloyd, R, Agouris, I, and Keogh, JWL. Effect of load positioning on the kinematics and kinetics of weighted vertical jumps. *J Strength Cond Res* 26: 906–913, 2012.
23. Tobin, DP and Delahunt, E. The acute effect of a plyometric stimulus on jump performance in professional rugby players. *J Strength Cond Res* 28: 367–372, 2014.
24. Turner, AP, Unholz, CN, Potts, N, and Coleman, SGS. Peak power, force, and velocity during jump squats in professional rugby players. *J Strength Cond Res* 26: 1594–1600, 2012.
25. Vanrenterghem, J, Lees, A, and De Clercq, D. Effect of forward trunk inclination on joint power output in vertical jumping. *J Strength Cond Res* 22: 708–714, 2008.